Multi-scale plasticity in hierarchical microstructures: modeling laminated morphologies with application to martensitic steels

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ABSTRACT

A broad class of materials, like metals and polymers, exhibit hierarchical microstructures. In the specific case of martensitic steels, lath martensite grains have a well defined internal (crystalline) hierarchical substructure [1], i.e. packets, blocks, laths. Thin layers of retained austenite may also be present between the laths. They form parallel stacks together with the laths, which result in laminated microstructures.

We have recently shown [2], by using standard crystal plasticity, that the presence of very small volume fractions (5%) of interlath retained austenite may be a plausible explanation of the apparent ductility of martensitic subgrains. The austenite acts like a “greasy” plane on which stiffer laths can slide. The role of the orientation relationship between the BCC laths and FCC austenite layers is fundamental.

By means of an upscaling technique, we have validated the model [3] with experimental results on a martensitic steel. We have shown that, by accounting for the presence of interlath austenite, the main features of the experimentally observed deformation behavior (stress-strain curve, slip activity and roughness pattern) are qualitatively well reproduced by the model. By neglecting the presence of interlath austenite, the observed experimental stress-strain response is not captured.

The two-scale model used in [3] is computationally too expensive. Furthermore, just a limited number of slip systems in the austenite carry most of the plastic deformation, i.e. those parallel to the direction of the laminate. This calls for a reduction of the model in [3]. We have formulated a framework, in the finite deformation setting, which is suitable when a limited number of slip systems is active and some plasticity occurs along the remaining spatial directions [4]. We couple crystal plasticity and isotropic plasticity formulations by means of a projector operator. In the limit of no active slip systems, isotropic plasticity is recovered, while standard crystal plasticity is obtained when five linearly independent slip systems are active.

The model has been validated on the results of [3]. The main features of the physics of the problem (i.e. stress-strain response and plastic activity) are correctly reproduced with computational speed-ups up to a factor of 10. This allows to use the model for RVE's with multiple martensitic islands.

On top of martensitic microstructures, this framework can be applied to the modelling of metals and polymers in which plasticity is constrained to occur along preferential directions or slip systems, due to the specific crystalline nature of the materials or due to the morphology of the crystal itself, like in laminated microstructures.

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